PERFORMANCE BASED CHARACTERISATION

OF BITUMINOUS BINDERS

A thesis submitted in the partial fulfillment

of the requirements for the degree of

BACHELOR OF TECHNOLOGY

IN

CIVIL ENGINEERING

BY

MAITHILI MOHANTY (108CE037)

UNDER THE GUIDANCE OF

PROF.MAHABIR PANDA

DEPARTMENT OF CIVIL ENGINEERING

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA

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CERTIFICATE

This is to certify that the thesis entitled, "**PERFORMANCE BASED CHARACTERISATION OF BITUMINOUS BINDERS**" submitted by **Ms. MAITHILI MOHANTY (ROLL-108CE037)** in partial fulfillment for the award of the Degree of Bachelor of Technology in Civil Engineering, National Institute of Technology, Rourkela is an authentic work carried out by her under my supervision and guidance.

To the best of my knowledge, the matters enclosed in the thesis have not been submitted to any other university/Institute for the award of any Degree or Diploma.

DATE: - 09-05-2012

PLACE: - ROURKELA

PROF.MAHABIR PANDA

DEPARTMENT OF CIVIL ENGG.

NIT ROURKELA

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DATE: - 09-05-2012

PLACE: - ROURKELA

MAITHILI MOHANTY

108CE037

DEPARTMENT OF CIVIL ENGG.

NIT ROURKELA

ABSTRACT

Bitumen is predominantly used to construct pavements for roads, highways, and airports. Due to the viscoelasticity nature of bitumen, it plays a predominant role in the performance of the pavements where temperature and rate of load application have a great influence. In India, the specifications for bituminous binders rely on different empirical tests which have almost no significance on their performance characteristics.

In this research, an attempt has been made to study the rheological properties of bituminous binders commonly used in India, at high and intermediate field temperatures in terms of their performance characteristics. Considering several factors that affect the behavior of bituminous binders, the effects of variations in temperature, rate of loading and amount of loading have also been studied. The changes in the properties of commonly used grades (80-100 and 60-70) bitumen both unmodified and modified with crumb rubber has been studied. Also the effect of ageing on the rheological properties of bituminous binders has been studied. It has been observed that the binders used in this investigation satisfy the rutting and fatigue criteria as stipulated under the new concept of Superior Performing Asphalt pavement (super pave).

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LIST OF ABBREVIATIONS

CRMB: Crumb Rubber Modified Bitumen

PAV: Pressure Ageing Vessel

TFO: Thin Film Oven

SHRP: Strategic Highway Research Program

DSR: Dynamic Shear Rheometer

AASHTO: American Association of State Highway and Transportation Officials

MSCR: Multiple Shear Creep Repeated Test

DE: Dissipated Energy

<u>CHAPTER 1</u>

INTRODUCTION

1.1.GENERAL

With the rapidly expanding Indian road transportation infrastructure, the road network is undergoing a challenging development under National Highways Development Programmes (NHDP), State Highways Improvement Programmes (SHIPs), Bharat Nirman, Pradhan Mantri Gram Sadak Yojana (PMGSY) etc. where a huge sum of money is being invested by the Indian Government in order to reach excellent pavement performance.

The flexible pavements, which have bituminous layers in top, are more preferred in India as these are less expensive with regard to both initial and maintenance costs. Bituminous binders commonly used in surface courses are unmodified binders such as 60/70 or 80/100 bitumen (depending on the climatic conditions) and modified binders such as CRMB. The present Indian specifications have cleared recommendations about acceptance criteria for these binders considering different physical tests which are all empirical in nature. For example, in India, penetration tests which is a basically an empirical test used to indicate the hardness or softness of a binder by determining the penetration of a standard needle under 100 grams of loading for 5 seconds at 25°C . This test has no relation of bitumen with regard to its actual field performance. While there is great demand and consequent investment on bituminous road infrastructures, it is essential to think of use of performance based specifications of materials used in these constructions so that the ultimate objectives of such huge investments may be justified.

Recently, Strategic Highway Research Program (SHRP) introduced performance based binder specification in total quality perspective based on the shear susceptibility parameters, addressing each type of pavements failure. For India, the failure modes may be identified as critical pavement distresses resulting from rutting and fatigue cracking only as low temperature effects are only limited to only small part. Considering this, an attempt is made in this project to study the performance related characteristics of one unmodified bitumen i.e. bitumen 80/100 and a modified binder i.e. CRMB 55 which are commonly used for paving in our country. The main objective of this study is to relate the performance characteristics of these binders to the binder type. It is expected that this can explore the scope of development of new specifications for paving binders in India.

1.2.INDIAN SCENARIO AND ASSOCIATED PROBLEMS

In India, the bitumen grading is practised on the basis of penetration test, which is conducted at a temperature of 25°C, and does not indicate viscous/elastic behavior of bitumen at the test temperature.

The most common problem associated with the performance of bituminous pavements throughout the world including India is rutting during hot summer. The bitumen becomes soft at 60 to 70°C (typical road surface temperature on a hot summer day) and starts to push and shove under loaded truck tyres leading to rutting and corrugations in the wheel tracks of the roadway. When temperature falls or after a sudden cold front, bituminous pavements become too brittle and fatigue cracks occur when excessively loaded.

1.3.OBJECTIVE

- This project attempts to understand and investigate the rheological properties of bituminous binders with the aim of determining the resistance to fatigue cracking and rutting in pavements.
- The changes of rheological properties of commonly used unmodified bitumen 80/100 & 60-70 and modified bitumen (Crumb Rubber) have been studied before and after ageing using ***Pressure Aging Vessel*** **(PAV**) and ***Thin Film Oven*** **(TFO).**

- An investigation to describe the linear viscoelastic properties of a series of bitumen (unmodified and CRMB 55) at various frequencies and temperatures. The results are to be analyzed in terms of complex shear modulus and phase angles curves at constant temperature.

1.4.SCOPE OF THE WORK

The study work investigates different areas including performance based characterization of bituminous binders. Three types of binders are used which are commonly used in India i.e. CRMB 55, 80-100 and 60-70 grade bitumen. The rheological tests and creep tests were undertaken using a dynamic shear rheometer (DSR) apparatus based on the fundamental of dynamic mechanical analysis. The rheological properties of modified binders help to identify the importance of using modifiers in pavement industries. Ageing of bitumen was done using the TFO for short term ageing and PAV for long term ageing and effect of ageing on the rheological parameters are studied. All tests were conducted at Transportation laboratory, NIT ROURKELA.

1.5. THESIS LAYOUT

The work is organized in six Chapters.

Chapter 1: is an introductory chapter outlining the problem statement and the objectives of the research work. The scope of the study is clearly stated in this chapter as well as a layout of the thesis.

Chapter 2: provides an extensive literature review beginning with an introduction and brief summary regarding to composition and chemistry of bitumen. Evaluation of the rheological and visco- elastic properties of bitumen binder using dynamic mechanical analysis as well as characterization of the mechanical properties of bitumen are presented in this chapter.

Chapter 3: deals with bitumen rheology. This chapter contains the basic fundamentals of dynamic shear rheometer and describes two main rheological parameters i.e. Complex shear modulus and phase angle.

Chapter 4: contains experimental methods dealing with short term ageing with the help of Thin Film Oven and long term ageing by Pressure Vessel Ageing. This chapter also contains methods to characterize the rheological behavior of modified and unmodified bitumen and evaluate the fatigue behavior.

Chapter 5: describes the rheology and fatigue laboratory test results for modified and unmodified binder (both aged and unaged).

Chapter 6: includes a list of conclusions as well as the references collected.

CHAPTER 2

LITERATURE SURVEY

2.1. INTRODUCTION

The purpose of this chapter is to review the literature of rheological properties of bituminous pavements. This literature review consists of four parts; the first part deals with the chemical composition and viscoelastic properties of bitumen. The main topic in the second part is to classify the common flexible pavement distresses. The third part describes the ageing processes in the pavements. Last part describes the laboratory approaches used to evaluate the rheological properties of the bituminous binders.

2.2. FLEXIBLE PAVEMENT

A pavement is the durable surface material laid down on an area intended to sustain vehicular or foot traffic, such as a road or walkway. A pavement is classified in general in two categories, i.e. namely a flexible pavement and a rigid pavement. The flexible pavement consists of granular layers of superior quality in upper layers with a preferably bituminous topping and the total structure bends or deflects due to traffic loads, while a concrete pavement consists of a cement concrete slab over occasional granular layers. The flexible pavements are subjected to most serious distresses such as rutting which occurs at high temperatures and cracking which occurs at intermediate and low temperatures. These distresses are responsible for reducing the service life of the pavements and increasing the maintenance costs (Terrel, R. L., 1971). Current study is focused on the evaluating the rheological parameters of the bituminous binders in order to improving the rutting and fatigue cracking resistance of the binders.

The performance of the flexible pavements depends on the main component, bitumen which controls the viscoelastic properties during production in the plant and service on road. Their mechanical behavior is dependent on both the temperature and rate of loading. At low temperatures and short loading times, bitumen behaves as elastic solids while at high temperatures and long loading times, they behave as simple viscous liquids. At intermediate temperatures and loading times, the behavior is more complex. In order to understand the complex behavior of bitumen binder, one must understand the nature of bituminous materials.

2.3. ELEMENTARY ANALYSIS OF BITUMINOUS MATERIALS

Bitumen being a product from the distillation columns in the crude oil refineries is considered to be made up of asphaltenes, resins and oils. The elementary analysis of bitumen shows that it is composed of atoms of carbon and hydrogen; between 90 and 95 percent hydrogen and carbon atoms (Whiteoak C. D., 1990). The remaining 5 to 10 percent of the atoms in the material consist of two types:

- Heteroatoms
- Metals

The elementary analysis is presented in the table 1.

COMPONENT	PERCENTAGE %
Carbon	80-88
Hydrogen	8-11
Sulphur	0-6
Oxygen	0-1.5
Nitrogen	0-1

Table 1.Elementary Analysis of the bituminous materials

All these atoms combine to form molecules, through the formation of strong covalent bonds. These molecules can then interact with one another through the formation of other, much weaker types of bonding; requiring little energy to break and highly susceptible to heat and mechanical forces (Jones R. David, 1994). The types of weak bonds are:

- Pi-pi bonding
- Hydrogen or polar bonding
- Van der Waals bonding

2.4. CHEMICAL GROUPS OF BITUMEN

Robert N. H. et al (2000) explained that bitumen is composed of two major chemical groups called asphaltenes and maltenes. The main chemical composition for bitumen is presented below in figure 1:

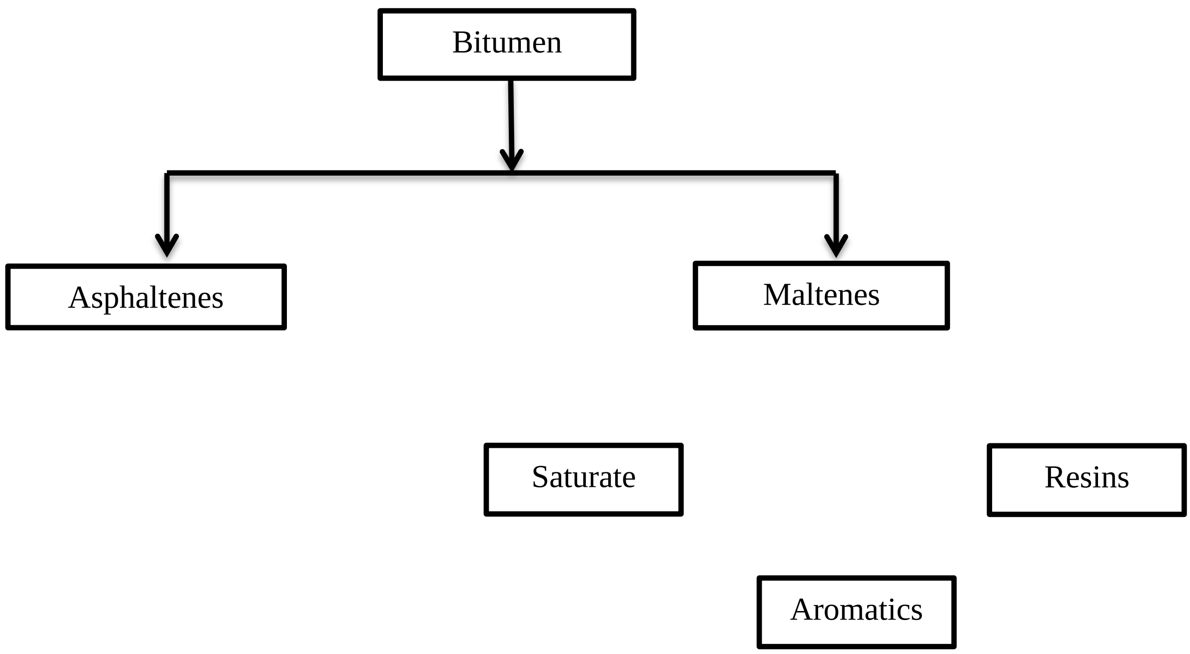

Figure 1. Chemical Composition for bitumen

Robert N. H. et al (2000) defined asphaltenes as highly polar, complex aromatic materials with higher molecular weight than maltenes. Bitumen with higher asphaltenes content will have higher softening points, higher viscosities and lower penetrations; thereby bitumen becomes harder. Maltenes are divided into three components. 5-10% bitumen includes both waxy and non-waxy saturates. Robert N. H. et al (2000) explained that the polar nature of the aromatics gives fluidity and viscosity to the bitumen. Resins give adhesion properties and ductility for the bituminous materials.

2.5. VISCOELASTIC PROPERTY OF BITUMEN

Viscoelastic material defined as material which store and dissipate mechanical energy in response to a mechanical stress. Robert N. H. et al (2000) described that bitumen's mechanical behavior depend on both on the temperature and rate of loading. The response of elastic, viscous and viscoelastic material under constant stress loading are presented in figure 2. Figure 2(a) shows a constant load is applied to an elastic material, the strain of the material is proportional to the applied stress and when the load is withdrawn, there is a complete regain to the original position. Figure 2(b) shows the behavior of a viscous material in which the strain of the material increases over time under constant stress. Figure 2(c) describes the behavior of a viscoelastic material in which a constant stress increases the strain over a long time and when the applied stress is removed, the material fails to attain its original position leading to permanent deformation.

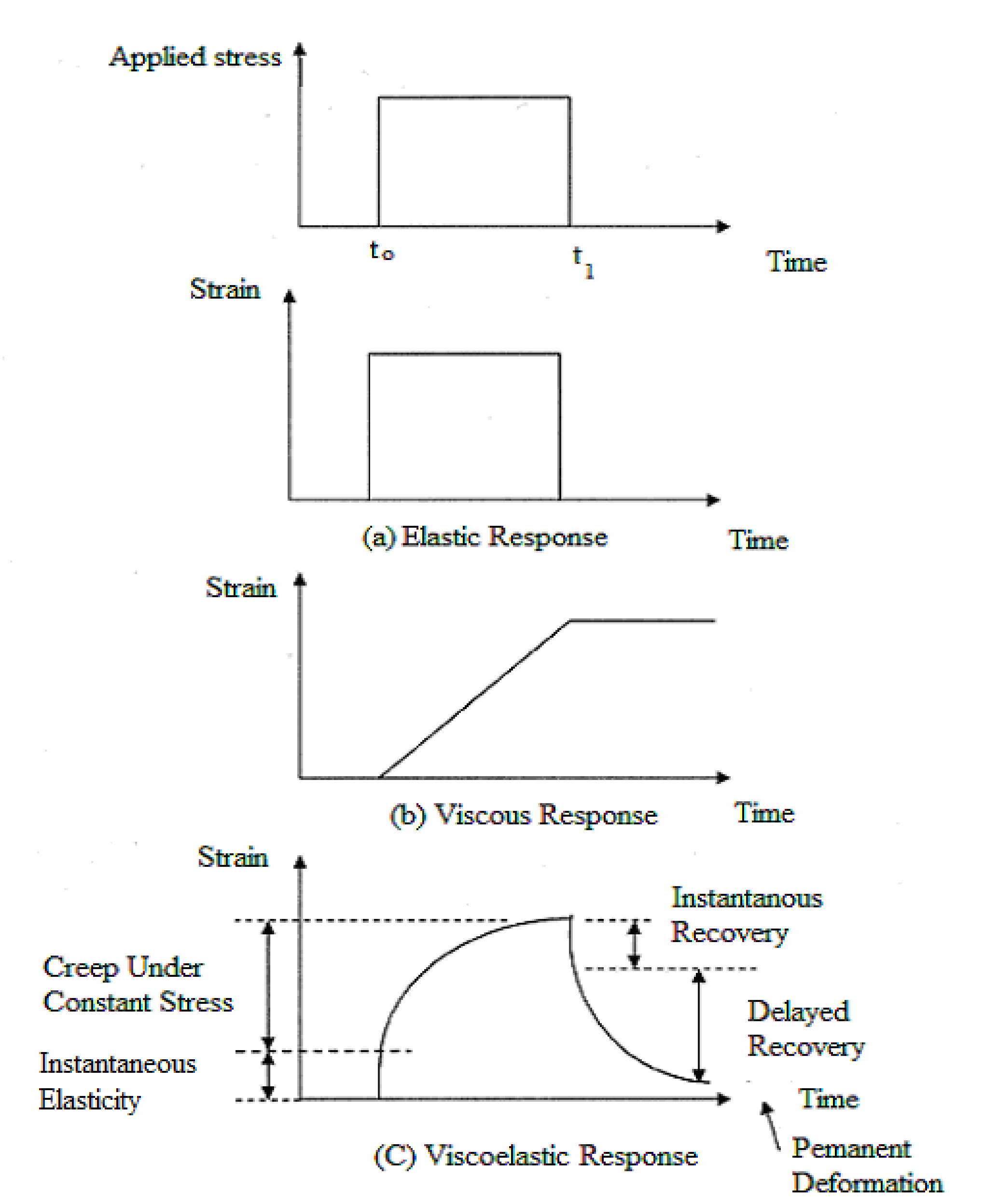

Figure 2. Idealized response of elastic, viscous and visco-elastic material under constant stress loading (Van der Poel, 1954)

2.6. BITUMEN MODIFIERS

Modification of bitumen is a technique of improving the properties of base bitumen when the material does not meet climate, traffic and pavement structure requirements. Isacsson U. (1995) reported that polymer modified bitumen has been used for a long time in order to achieve better performance. Roberts et al. (1991) described that the technical reason for using modifiers in bitumen are to produce stiffer binder at high service temperature to resist rutting as well as to obtain softer binders at low temperatures to minimize fatigue cracking in the pavements.

Whiteoak C. D., 1990 explained that modifiers stiffen the bitumen which directly affects the pavement performance.

2.7. AGEING OF BITUMEN

Bitumen ageing is a very complex process leading to hardening of bitumen and embrittlement, both in application and in service. It is generally agreed that one of the most important factors that causes pavements to crack and disintegrate is ageing phenomena of bituminous binders. Hardening of the binder occurs in two different stages. The first stage is short-term aging, due to loss of binder volatile components during mixing and is considered as the significant and the highest aging stage. The second stage is long-term aging, because of oxidative hardening during service life which is related to the source or the chemical composition of the original binders. The fact has been proven by early studies on binder aging (Anderson (1994)).

2.8. RHEOLOGICAL PROPERTIES OF BITUMINOUS MATERIALS

Vinogradov, et al. (1980) defined rheology science as a part of continuum mechanics and it is the study of material deformation. Bahia and Davies (1994) used the rheological properties as an indicator for the pavement performance; at high temperature the rheological properties are related to the rutting behavior of pavements. The rheology at intermediate temperatures affects the fatigue cracking of pavements. There are many pavement distresses, which are believed to be related to the rheological properties of binders.

CHAPTER 3

BITUMEN RHEOLOGY

3.1. INTORDUCTION

Rutting and fatigue cracking are the most common modes of failure for bituminous pavements which are mainly related to the rheological properties of the binders. To study the major rheological properties, experimental investigations are carried out using dynamic shear rheometer.

3.2. EVALUATION OF BITUMEN PROPERTIES

Goodrich J.L. (1998) reported that bituminous material exhibit viscoelastic response and the performance of the flexible pavements depend on rate of loading and temperatures. There are two types of tests that can be used to measure properties of the bitumen; conventional physical testing methods and fundamental rheological tests. The empirical physical tests fail to characterize the performance of bitumen binders and are related to a narrow range of temperature. The performance of bituminous binders can be measured by means of rheological parameters because the tests can be done under wide range of temperature and frequency.

Bahia, et al. (1993) presented in the research conducted for the Strategic Highway Research Program (SHRP), a new testing method to characterize the rheological properties of binders. The benefit of this technique is that it provides measurement of rheological properties at different frequencies with wide temperature range and is directly related to the field performance.

3.3. DYNAMIC SHEAR RHEOMETER

Dynamic shear rheometer is used to measure visco-elastic properties at high and intermediate temperature. This device employs a dynamic oscillatory load, where sinusoidal shear stress is applied in the form of sinusoidal time function. The bitumen's sample is sandwiched between two parallel plates where the lower plate is fixed and upper plate is movable. The dynamic load can be presented as sinusoidal time function, in the following equation:

$$\boldsymbol{\tau} = \boldsymbol{\tau o}\ \mathbf{si\ n}(\ \boldsymbol{\omega t})\text{--------------------------- } 3.1$$

The test simulates the shearing action of traffic at a certain speed and two important rheological parameters are determines which are used to predict pavement performance.

- the complex shear modulus (G*) and
- the phase angle (δ).

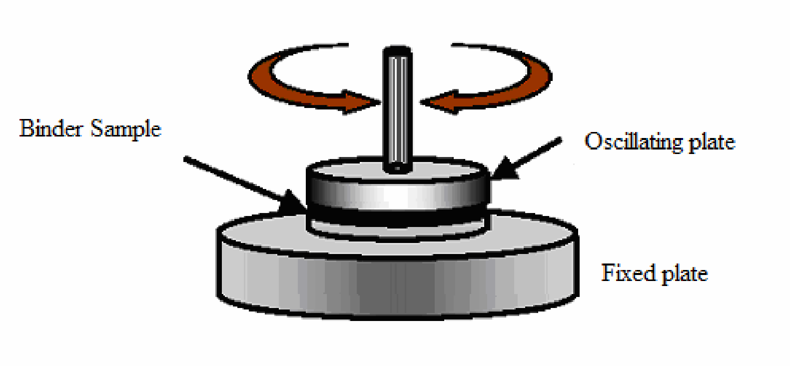

Figure (3.1) Dynamic Shear Rheometer after (Bahia, 1993)

Roberts, et al., (1996) mentioned that the data acquisition unit records the test temperature, applied load, loading frequency and deflection angle during the test cycles, then directly sends the test data to the personal computer which calculates the rheological parameters such as the shear stress, shear strain, complex modulus and phase angle and presents it in the form of table and figure.

3.3.1. Rheological Properties

Briscoe (1987) demonstrated the advantage of using (DSR) to describe the viscous and elastic behavior of bituminous binders at high and intermediate service temperatures. From the rheological test, two main parameters are obtained i.e. complex shear modulus (G*) and phase (δ). Complex modulus (G*) is defined as the total resistance of the binder to deformation when repeatedly sheared. The complex shear modulus (G*) consists of two components;

- Storage modulus, (G′): - It is the elastic (recoverable) component, and is related to the amount of energy stored in the sample during each testing cycle.
- Loss modulus, (G″): - It is the viscous (non-recoverable) component, and related to the energy lost during each testing cycle through permanent flow or deformation.

3.3.1.1. Dynamic Complex Shear Modulus (G*) & Phase Angle (δ)

Bahia et al (1995) identified the relationship between the complex shear modulus (G*), storage modulus (G′), loss modulus, (G″) and phase angle (δ), graphically as presented in figure (3.2) and described mathematically as shown from equation (3.2) to (3.6).

Time lag between applied stress and resulting strain, which is define as phase angle can be used to describe the viscoelastic behavior of bitumen binder which is shown graphically in figure (3.3).

- At high temperature, a substance is purely viscous then the phase angle (δ) is 90° that means G’ = 0 and G’’ = G*.
- At low temperature, a substance is purely elastic then the phase angle (δ) is zero that means G’ = G* and G’’ = 0.

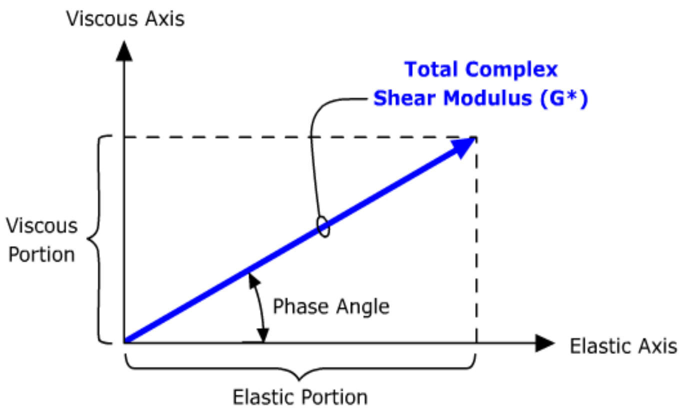

Figure (3.2) Relationship between Complex Shear Modulus (G*), Storage Modulus (G′), Loss Modulus (G″), and Phase angle (δ) after (Bahia, 1993)

$$G^* = \tau_R / \gamma_R \longrightarrow 3.2$$

$$G^* = G' + iG'' \longrightarrow 3.3$$

$$\tan(\delta) = G''/G' \longrightarrow 3.4$$

$$\tau_R = 2T / \Pi R^3 \longrightarrow 3.5$$

$$\gamma_R = R\,\theta / h \longrightarrow 3.6$$

Where:

τ_r: Absolute value of the peak-to-peak shear stress [Pa]

γ_r: Absolute value of the peak-to-peak shear strain [%]

T_{max}: Maximum applied torque (load) [Pa]

G’: Storage modulus [Pa],

G’’: Loss Modulus Pa [Pa]

R: Radius of specimen plate [*mm*]

θ_{max}: Maximum deflection angle [*rad*]

h: Specimen height [*mm*]

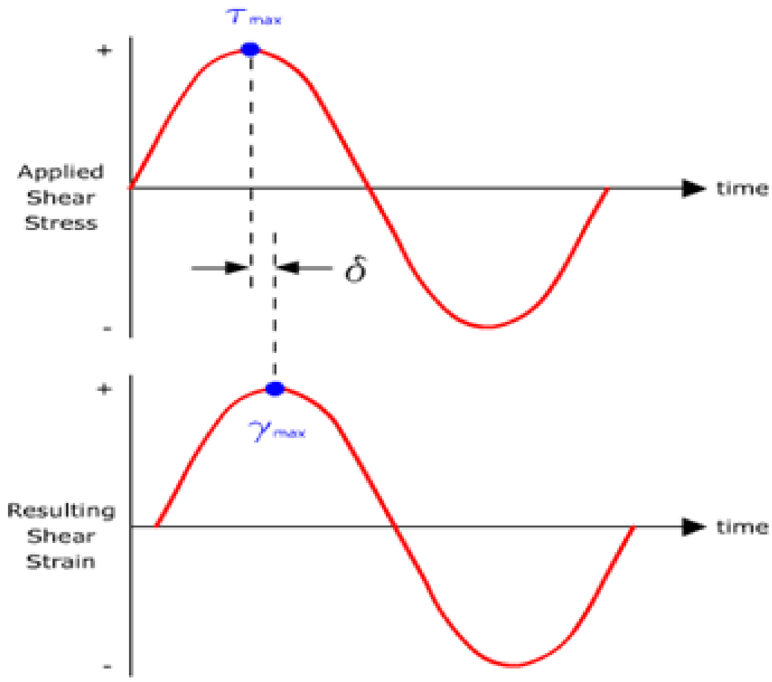

Figure (3.3) Viscoelastic material behavior for dynamic sinusoidal loading

3.4. TEST SPECIFICATION

The rheological tests were done according to the AASHTO Designation: T 315-08 (Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer (DSR)). This test method contains the determination of the dynamic shear modulus and phase angle of bitumen binder when tested in dynamic (oscillatory) shear using parallel plate test geometry. It is applicable to binders having dynamic shear modulus values in the range from 100 Pa to 10 MPa obtained between 6 and 88°C at an angular frequency of 10 rad/s. Dynamic shear rheometer, temperature unit and data acquisition unit are presented in figure (3.4)

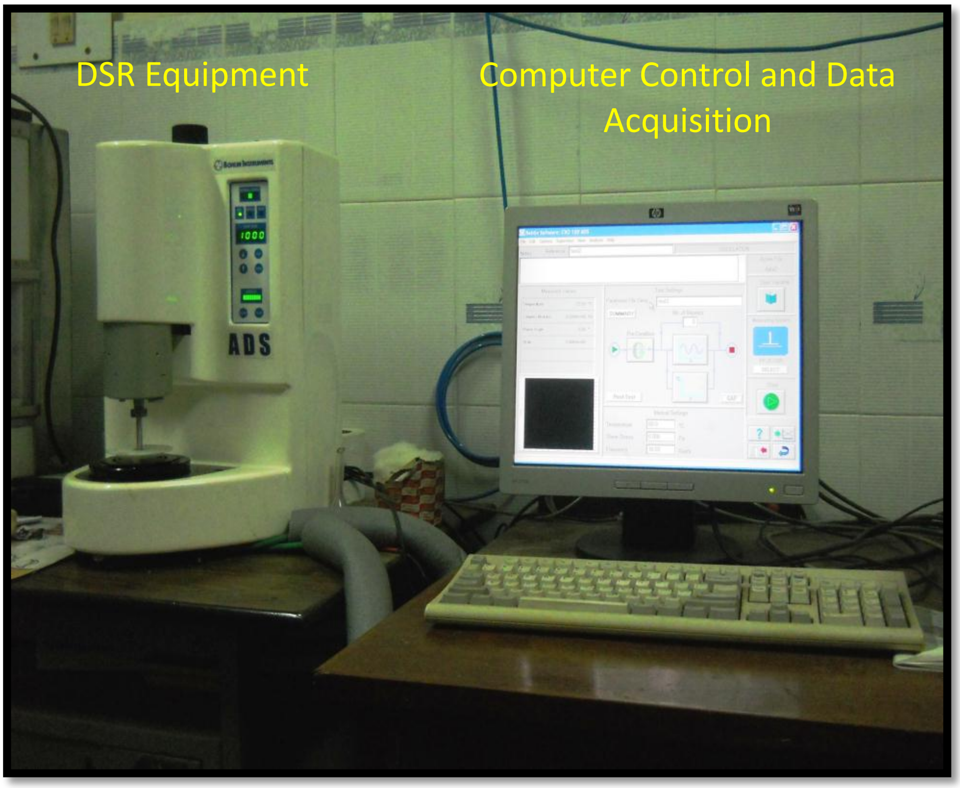

Figure (3.4) Dynamic Shear Rheometer

(NIT ROURKELA, Transportation Laboratory, Dept. of Civil Egg.)

3.5. BINDERS USED

Bitumen binders used in this study were (80-100 and 60-70) penetration grade bitumen, which is the most widely used in India. The second binder is crumb rubber modified bitumen which is also commonly used in India.

3.6. SPECIMEN GEOMETRY

The specimen geometry was chosen according to the test type, condition and specification. The specimen geometry at high temperature should have big diameter (25mm) with small thickness (1mm) to save the specimen from melting. At intermediate temperature the specimen should have small diameter (8mm) with high thickness (2mm) to prevent it from brittle crack.

25 mm diameter - 1mm thickness

High Temperature

8 mm diameter - 2mm thickness

Intermediate Temperature

Figure (3.5) (DSR) test samples for high temperature and intermediate temperatures

CHAPTER 4

EXPERIMENTATION

4.1. AGEING

- *<u>SHORT TERM AGEING (TFO)</u>*

The thin-film oven (TFO) test simulates short-term aging by heating a film of bitumen binder in an oven for 5 hours at 163° C (325° F).

Standard Test Methods: AASHTO T 179 and ASTM D 1754: Effects of Heat and Air on Asphalt Materials (Thin-Film Oven Test).

Figure (4.1) Thin Film Oven for short term ageing

- *<u>LONG TERM AGEING (PAV)</u>*

The basic PAV procedure takes TFO aged binder samples, places them in stainless steel pans and then ages them for 20 hours in a heated vessel pressurized to 2.10 MPa at 100°C. The standard Pressure Aging Vessel procedure is found in:

AASHTO R 28: Accelerated Aging of Asphalt Binder Using a Pressurized Aging Vessel (PAV).

Figure (4.2) Pressure Vessel Ageing for long term ageing

After 20 hours of treatment the samples are removed, degassed at 170° C and used for future testing. If not degassed, entrapped air bubbles may cause premature breaking in the DSR test.

Figure (4.3) Vacuum Oven for degassing

4.2. BITUMEN BINDER RHEOLOGY TESTS

The rheological properties and fatigue resistances were performed using three different binders. The tests were performed under range of frequency and temperatures.

1. Characterization of binders under standard conditions
2. Amplitude Sweep Test
3. Frequency Sweep Test
4. Temperature Sweep Test
5. Multiple Shear Creep Recovery Test
6. Fatigue behavior test

1. <u>Characterization of binders under standard conditions</u>

The test is conducted under certain standard conditions as given by SHRP which is used to characterize the bituminous binders. The test conditions are 60°C temperature, 120 Pa stress, and 10 rad/sec frequency with the 25mm diameter plate having specimen thickness 1mm for unaged and TFO aged binders. For PAV aged binders, the test temperature was changed to 40° C with 8mm diameter plate having specimen thickness 2mm.

2. <u>Amplitude Sweep Test</u>

A stress sweep was first conducted to determine the flow behavior for different binders. Measurements were performed at 60°C for unaged and TFO aged binders and 40 ° C for PAV aged binders with a shear stress range from 10Pa to 10 kPa and at 10 Hz. The complex shear modulus G* versus stress/strain plot was used to determine the linear viscoelastic region.

3. Frequency sweep Test

Frequency sweep tests were performed on bituminous binders. The samples were all poured and trimmed at the PG temperature (60°C for unaged and TFO aged binders and 40° C for PAV aged binders). All of the frequency sweep tests were performed from 1 to 50 rad/s under a stress of 500 Pa.

4. Temperature Sweeps Test

Dynamic Shear Rheometer test was conducted by using a temperature sweep starting from 20ºC to 80ºC, while the frequency was fixed at 10 Hz under a stress of 500 Pa. Parallel plates with diameter of 8 mm and 2 mm gap were used.

5. Multiple Shear Creep Recovery Test

Using the Dynamic Shear Rheometer (DSR), an one-second creep load is applied to the short term aged binder sample (TFO aged). After the 1-second load is removed, then sample is allowed to recover for 9 seconds. The test is started with the application of a low stress (0.1 kPa) for 10 creep/recovery cycles then the stress in increased to 3.2 kPa and repeated for an additional 10 cycles.

6. Fatigue behavior test

Bituminous pavements exhibit fatigue cracking under repeated traffic load in the intermediate temperature range. One of the most important tests used to determine fatigue behavior for bitumen binder is oscillatory time sweeps test.

Bahia, H., and Anderson, D. A. (1993) explained that fatigue damage in viscoelastic materials can be evaluated using stored and dissipated energies. The energy balance is influenced by rheological properties of the binder, which are in turn functions of temperature and the rate of loading. In this study dissipated energy concept is used to determine the fatigue life for PAV aged binder. The dissipated energy as outlined by Pronk is given below:

$$W_i = \Pi * \tau^2 * \sin(\delta)/G^*$$

Where:

W_i: Dissipated energy per cycle

τ : Applied stress (Pa)

G *: Complex modulus (Pa)

δ: Phase angle (Degree)

The fatigue test was performed on long term (PAV) aged binder with 8-mm plates and 2.0 mm thickness. A time sweep was performed, in which an oscillating stress of 10 Pa and 10 kPa was applied with constant frequency 10 Hz.

Fatigue can be minimized by controlling the dissipated energy. The relationship between the fatigue life of a binder (N_f) and the energy input (W_i) is given by a conventional power law model:

$$N_f = K1 * (1/W_i)^{K2}$$

After the fatigue parameters are calculated, K1 and K2 are used to describe the fatigue behavior of the bitumen binder.

CHAPTER 5

ANALYSIS OF RESULTS

5.1. INTRODUCTION

This chapter demonstrates the rheological properties and fatigue behavior results for binder as well as brief analysis test data. The rheological properties of the different binders were characterized using dynamic shear rheometer over wide ranges of temperatures and frequencies. A summary of the test results is presented in tables and graphical form in the following sections.

5.2. Characterization of binders under standard conditions

- The test is conducted under certain standard conditions as given by SHRP which is used to characterize the bituminous binders.
- The following specifications are provided by SHRP for different binders:
  - ❖ To minimize rutting, the stiffness value G*/sin (δ) of the binder after TFO must be greater than 2.2kPa at the maximum 7-day average pavement design temperature.
  - ❖ To control possible tenderness, if ageing does not occur during construction, the stiffness value G*/sin (δ) of the original binder does not exceed 1.0 kPa at the same pavement temperature.
  - ❖ To minimize cracking, the stiffness value G* x sin (δ) of the binder after PAV must be less than 5000 kPa at the intermediate pavement design temperature. This is to minimize the work dissipated.

A summary of the test results is presented in Table 2.

Table 2. BINDER CHARACTERISATION UNDER STANDARD CONDITIONS									
	TEST CONDITIONS		RESULTS OBTAINED					REMARKS	
Binder Type	*Temperature °C*	*Angular Frequency rad/s*	*Phase Angle °*	*Strain*	*Complex Modulus Pa*	*G*/Sin(δ) Pa*	*G* x sin(δ)*	*Specifications*	*Remarks*
80-100	60	10.03	88.21	0.0487	4183.59	4185.64		>1kPa	Passed
crmb	60	10.03	76.13	0.014	8564	8822		>1kPa	Passed
TFO aged 80-100	60	10.03	87.89	0.0479	4594	4597.25		>2.2kPa	Passed
TFO aged crmb	60	10.03	74.91	0.0095	9120	9447.4		>2.2kPa	Passed
PAV aged 60-70	40	10.03	65.17	0.012	528400		479500	< 5000kPa	Passed
PAV aged 80-100	40	10.03	68.79	0.012	250400		233400	< 5000kPa	Passed
PAV aged CRMB	40	10.03	60.65	0.012	749700		653400	< 5000kPa	Passed

5.3. Stress Sweep Test Result

Stress sweep testing was carried out using the dynamic shear rheometer, which is used to determine the linear visco-elastic limits as a percentage decrease of the initial complex shear modulus value at selected temperature, frequency and the stress as illustrated in figure (5.1).

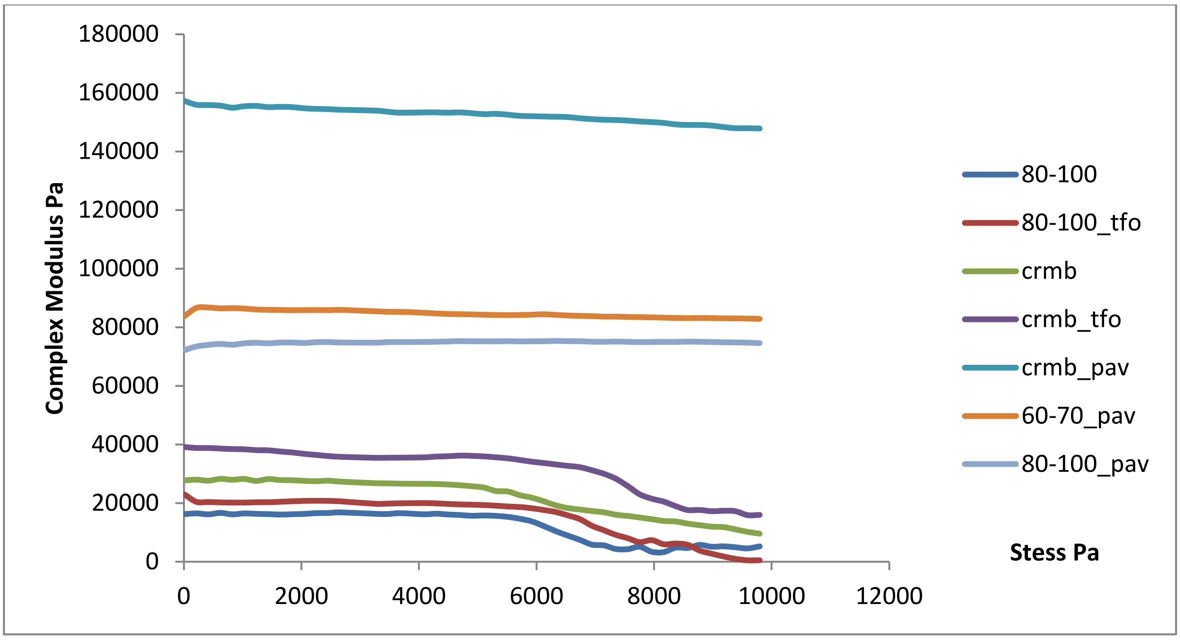

Figure (5.1) Complex shear modulus G* versus stress

The results of different binders were compared, which could help to determine the linearity limits. Based on the linear limits, the input parameter for other sweep tests is chosen for different bitumen binders.

For the majority of binders; it has been found that the linear range lies between 100 Pa to 8000 Pa. To make the tests much easier, the same stress level was chosen for all bituminous binders. Therefore, 500 Pascal was chosen as the constant stress used as input parameter for frequency sweep test for all binders.

5.4. Frequency Sweep Test Result

The highest loading frequency (50 Hz) was selected because it specified high traffic speeds, and the lowest testing frequency (0.1 Hz) was selected because it intended loading in slow moving traffic conditions.

The test results, complex shear modulus and phase angle at various frequencies for all binders are illustrated in Figures (5.2) to (5.5).

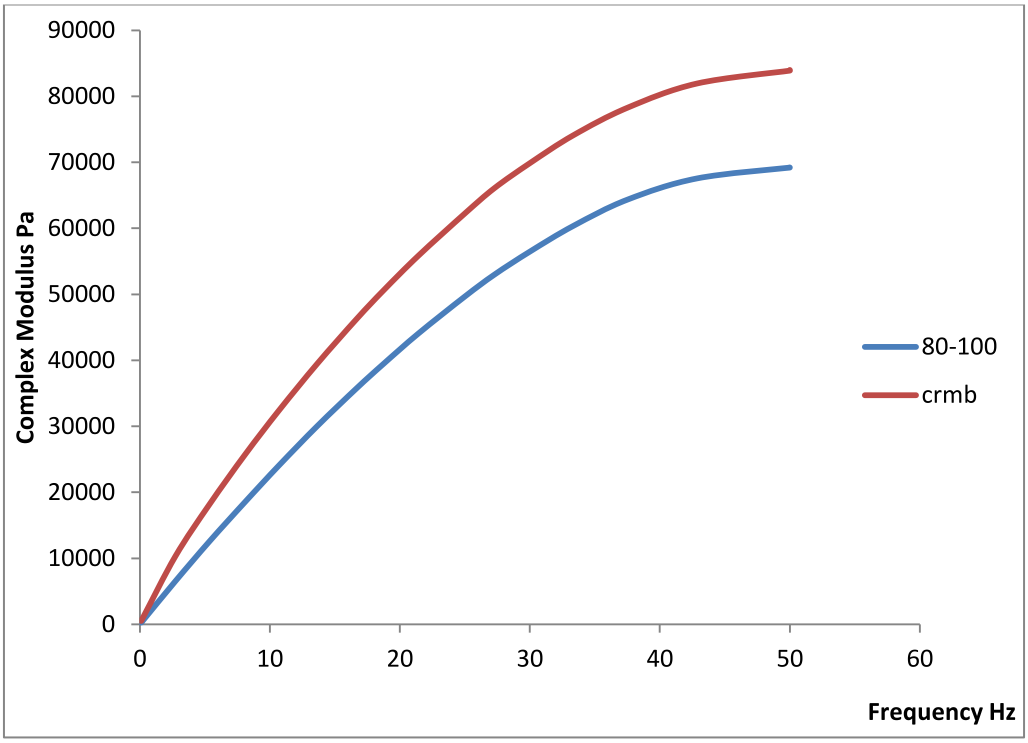

Figure (5.2) Complex modulus versus frequency

for neat bitumen

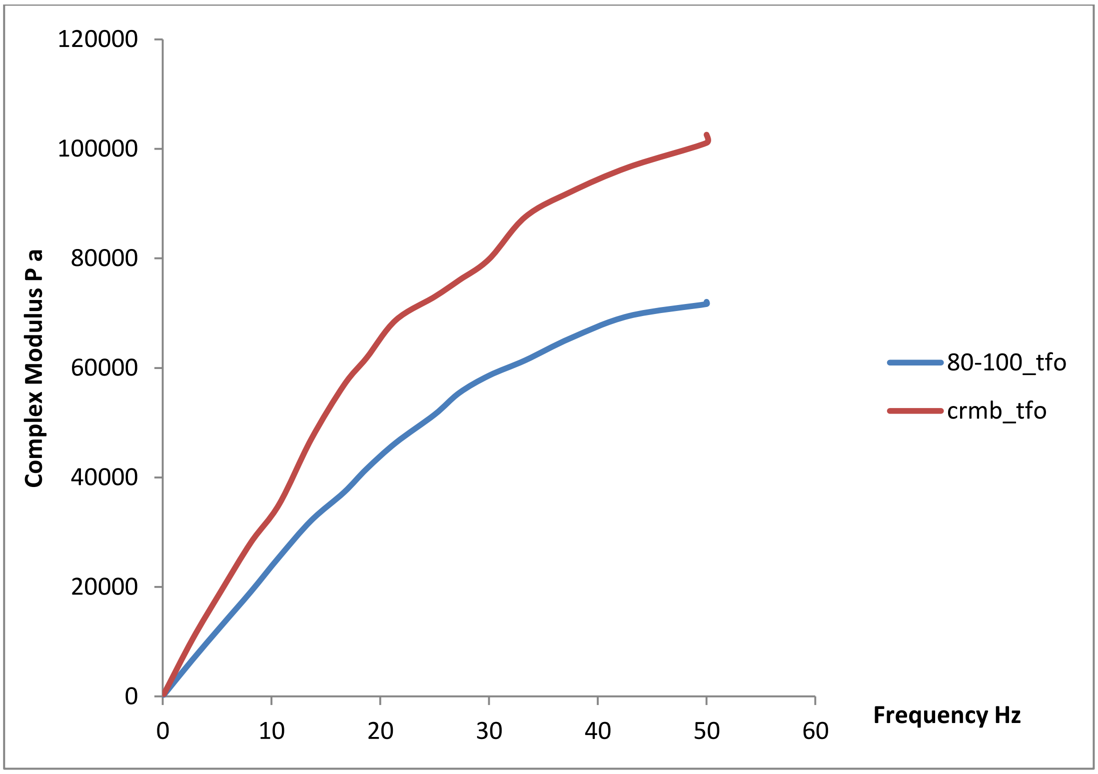

Figure (5.3) Complex modulus versus frequency for Short term aged bitumen

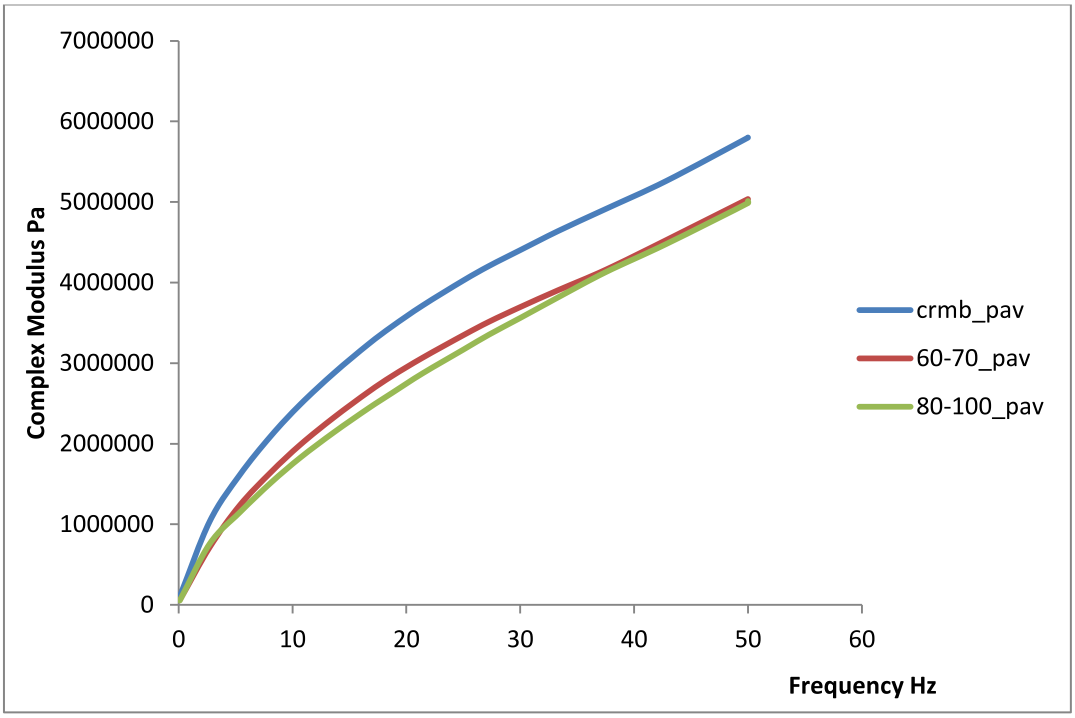

Figure (5.4) Complex modulus versus frequency for long term aged bitumen

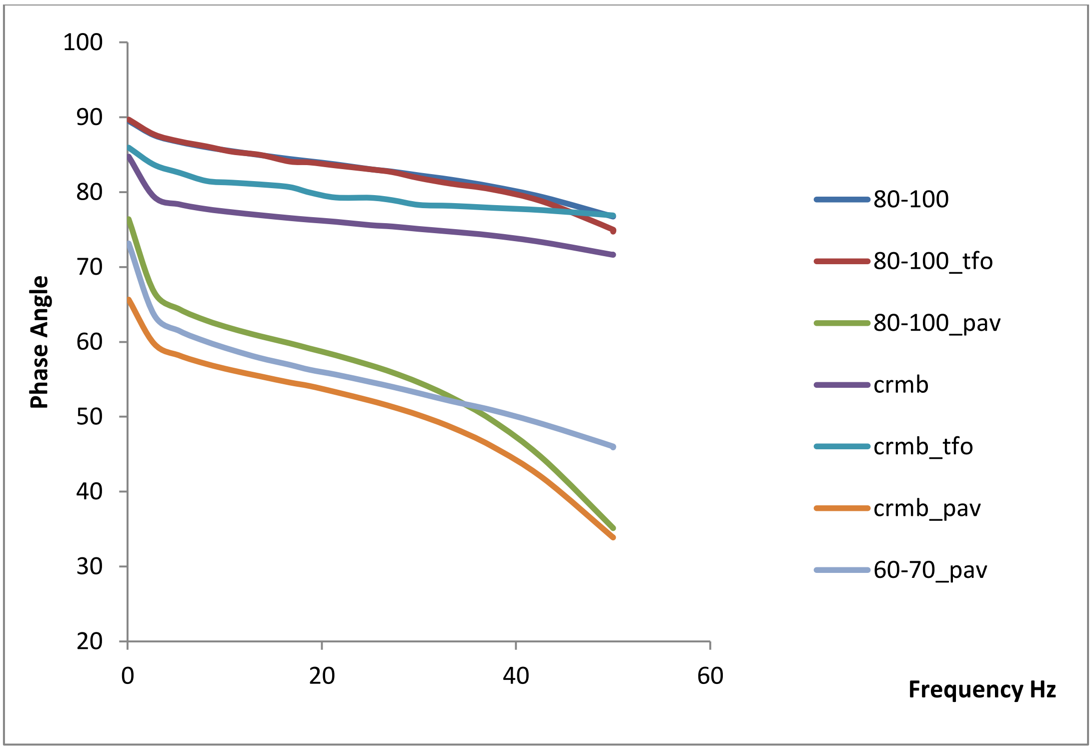

Figure (5.5) Phase Angle versus frequency

It clear from the result that general trend is that the shear modulus (G*) increases with the testing frequency and phase angle for the bitumen tested sample tends to decrease with the increases of testing frequency. From figure (5.2) to (5.4), it can be seen that the modified binder have high complex shear modulus and lower phase angle than base bitumen.

Oliver 1982 reported that when the crumb rubber is added to causes the absorption of aromatic oils thereby softening and swelling of the rubber particles. From the previous result it appears clearly that CRMB has less phase angle than base bitumen which directly affects the elastic recovery properties. In conclusion, the addition of crumb rubber as modifier to the base bitumen produces hard and elastic bitumen.

The complex modulus curves show the same general behavior for TFOT and PAV conditions. The PAV materials were obviously much stiffer than the TFOT and unaged samples over the entire range of frequencies which indicates that once the binder is aged sufficiently (PAV aged) the stiffness changes greatly with the frequency of loading.

Also the phase angles for PAV materials were much lower than that of the TFOT and unaged samples. Hence it is concluded that as the binder is aged it becomes stiffer and more elastic.

5.5. Temperature Sweep Test Result

Temperature has great effect on bitumen binder properties such as stiffness. As expected, shear modulus for all binders is a function of temperature: the higher the testing temperature, the lower the complex shear modulus.

The rheological properties in terms of complex shear modulus and phase angle are presented in Figure (5.6) to Figure (5.8).

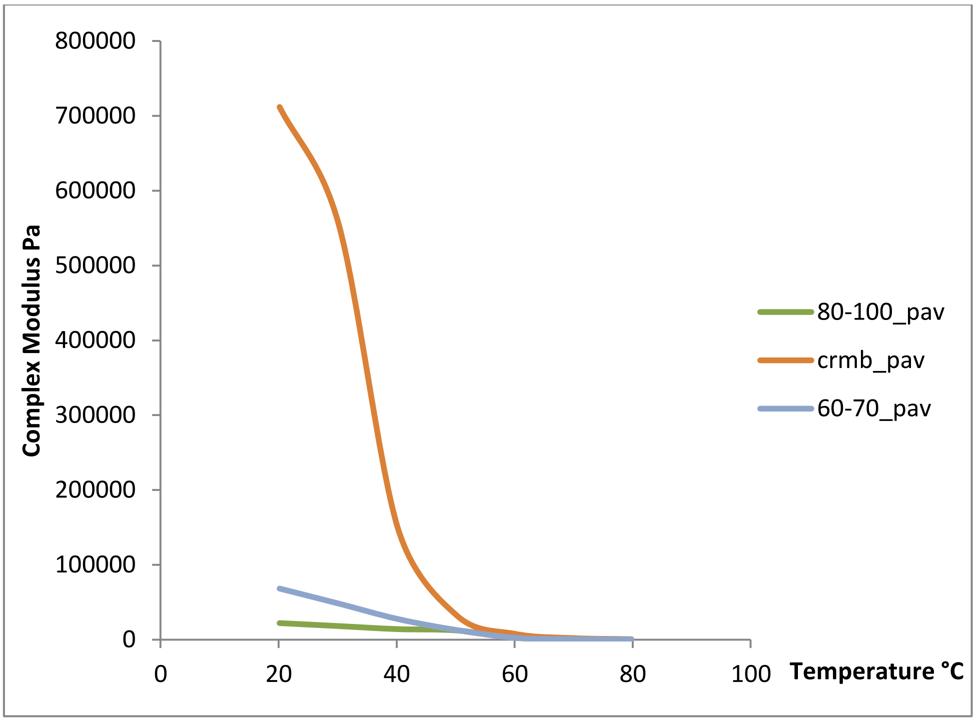

Figure (5.6) Complex Modulus versus temperature

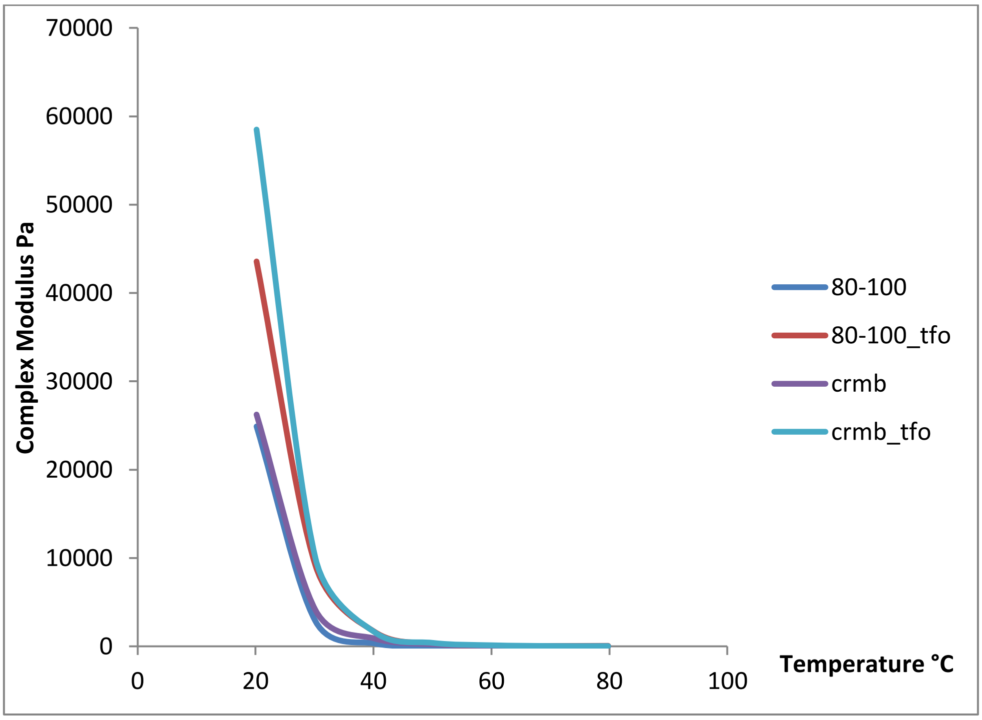

Figure (5.7) Complex Modulus versus temperature

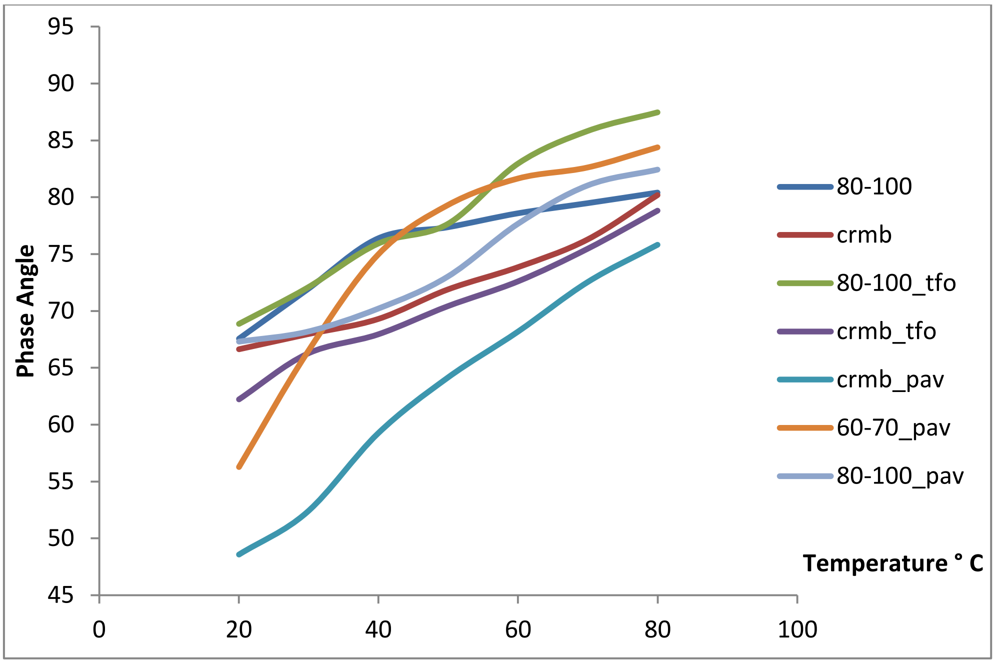

Figure (5.8) Phase angle versus temperature

From the result it is clear that when temperature is increased, the complex shear modulus decreases. The modified bitumen has higher complex modulus and lower phase angle than neat bitumen which means that it is absolutely stable. This means that using crumb rubber with neat bitumen increases the binder elasticity at high temperatures and improves the flexibility at low temperatures thereby lessening both rutting and fatigue cracking.

Robert N. H. et al (2000) found that when rubber is added to base bitumen, the elastomer absorbs the maltene content thereby increasing the asphaltene content. This is why the CRMB is harder than the base bitumen and this leads to an increased resistance to pavement rutting.

A significant decrease in phase angle is generally observed after ageing tests (TFOT, PAV) as compared with the original ones. Since phase angle is a measure of the ratio between loss modulus and storage modulus $Tan\delta = G`` / G`$ (loss tangent), the decreased phase angle implies that ageing leads to a greater increase in both storage modulus (elastic component, G`) than the increase in loss modulus (viscous component, G``) and hence, there occurs a variation from viscous material to elastic material, producing a harder binder.

Anderson (1994) described that as bitumen age, they incorporate oxygen to the chemically active atoms such as benzylic carbon. Hence volatisation of low molecular weight molecules takes place thereby strengthening the network in the binder and increasing the complex shear modulus.

5.6. Multiple Shear Creep Recovery Test

In the MSCR test, higher levels of stress & strain are applied to the binder, better representing what occurs in the actual pavements. The Jnr parameter (creep compliance) represents the rut resistance and the amount of recovered strain from the test identifies the presence of polymer.

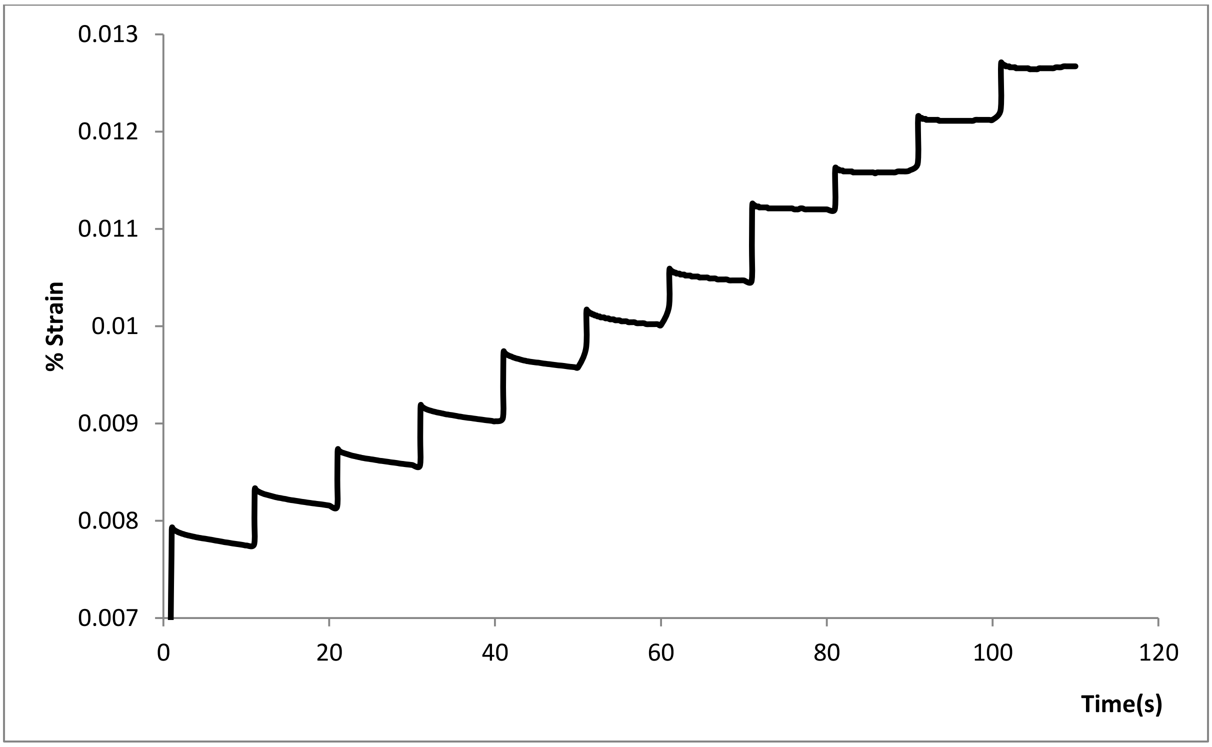

Figure (5.9) Unmodified Bitumen Binder Response to Repeated Loading.

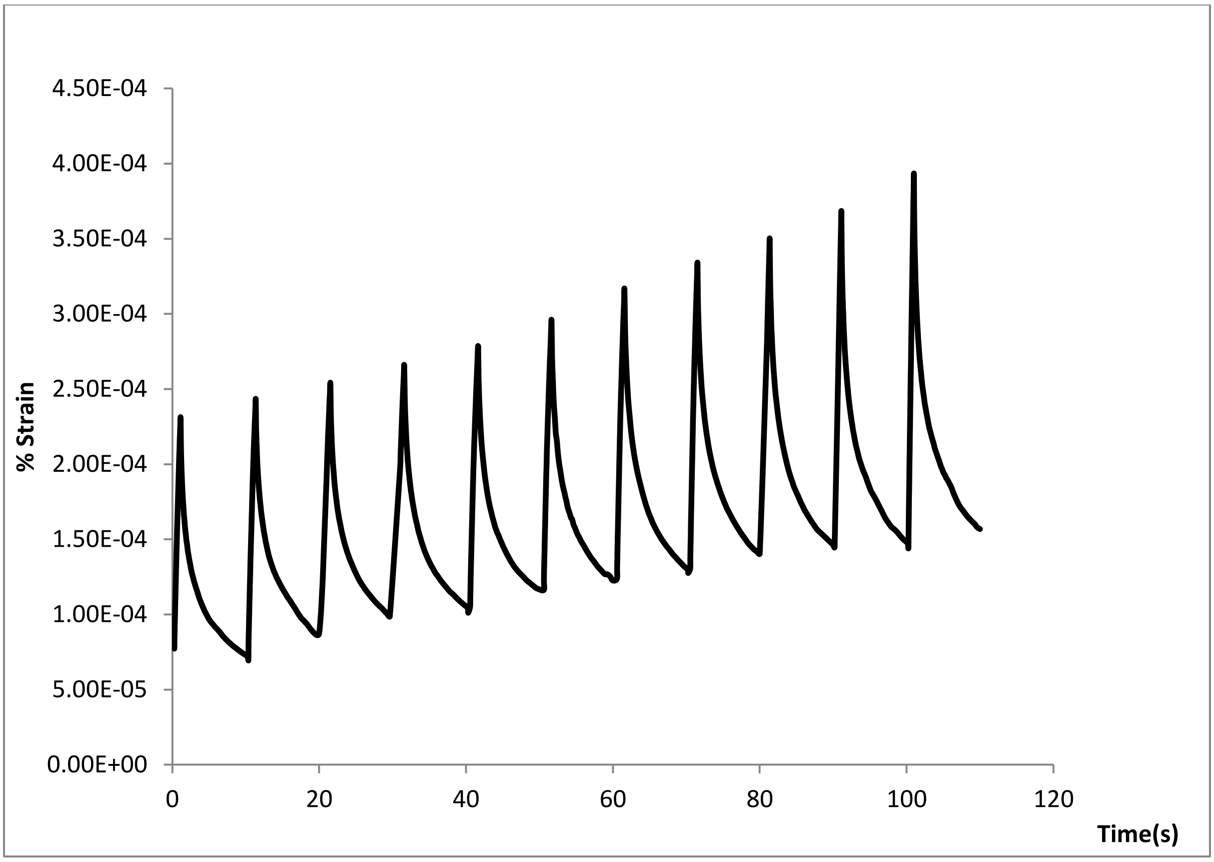

Figure (5.10). Modified Bitumen Binder Response to Repeated Loading.

This shows that the permanent strain that is accumulated of the neat binder is more than that of modified binder. Hence, this provides an indication of the delayed elastic response of the binder which is an indication that the binder has a significant elastic component at that test temperature.

From the above results, it is found that the elastic recovery in 80-100 binder is 0% and in CRMB is 68.22%. So, the 80-100 binder does not recover its original shape when tension is released but CRMB recovers to its original when load is withdrawn at a faster rate. This degree of elastic recovery was used as an indicator of permanent deformation in pavement materials. The MSCR calculations are given below:

Table 3. MSCR Recovery Calculations (80-100)

Stress Cycle	γ0	γc	γ1	γr	γ10	Recovery
0	0.000124	0.01264	0.012516	0.01267	0.012546	-0.2397
1	0.000119	0.01209	0.011971	0.01212	0.012001	-0.2506
2	0.000125	0.01157	0.011445	0.0116	0.011475	-0.26213
3	0.000117	0.01121	0.011093	0.0112	0.011083	0.090145
4	0.000112	0.01054	0.010428	0.01047	0.010358	0.671276
5	0.000109	0.01013	0.010021	0.01001	0.009901	1.197497
6	0.00011	0.01013	0.01002	0.009576	0.009466	5.529108
7	0.000105	0.009155	0.009051	0.009576	0.009472	-4.65168
8	9.93E-05	0.008707	0.008608	0.008573	0.008474	1.556748
9	9.84E-05	0.008308	0.00821	0.008156	0.008058	1.851498
10	9.72E-05	0.007909	0.007812	0.007746	0.007649	2.08659
						0.688978

Table 4. MSCR Recovery Calculations (CRMB)

Stress Cycle	γ0	γc	γ1	γr	γ10	Recovery
0	1.94E-05	0.000394	3.74E-04	0.000157	1.37E-04	63.28
1	1.81E-05	0.000369	3.50E-04	0.000144	1.26E-04	64.10
2	1.76E-05	0.00035	3.32E-04	0.000133	1.15E-04	65.42
3	1.64E-05	0.000334	3.17E-04	0.000124	1.07E-04	66.25
4	1.53E-05	0.000317	3.01E-04	0.000112	9.63E-05	68.03
5	1.49E-05	0.000296	2.81E-04	0.000102	8.71E-05	68.97
6	1.41E-05	0.000278	2.64E-04	0.000102	8.79E-05	66.71
7	1.35E-05	0.000266	2.52E-04	8.74E-05	7.39E-05	70.69
8	1.31E-05	0.000254	2.41E-04	8.18E-05	6.87E-05	71.46
9	1.24E-05	0.000243	2.31E-04	7.79E-05	6.55E-05	71.62
10	1.21E-05	0.000231	2.19E-04	6.94E-05	5.73E-05	73.88
						68.22

5.7. Fatigue behavior

Test results include measurements of complex modulus (G*) and phase angle (δ) as a function of the time in the DSR. Excel work sheets were used to calculate dissipated energy to get number of cycles to failure. The relation between DE and number of load cycles to failure were used to determine fatigue life parameter K1 and K2. From the result analysis given in figure (5.11), it can be seen that a linear fit is obtained between dissipated energy and number of cycles. The classic power law relationship is used to establish the relationship relating number of failures to dissipated energy as given in table (5).

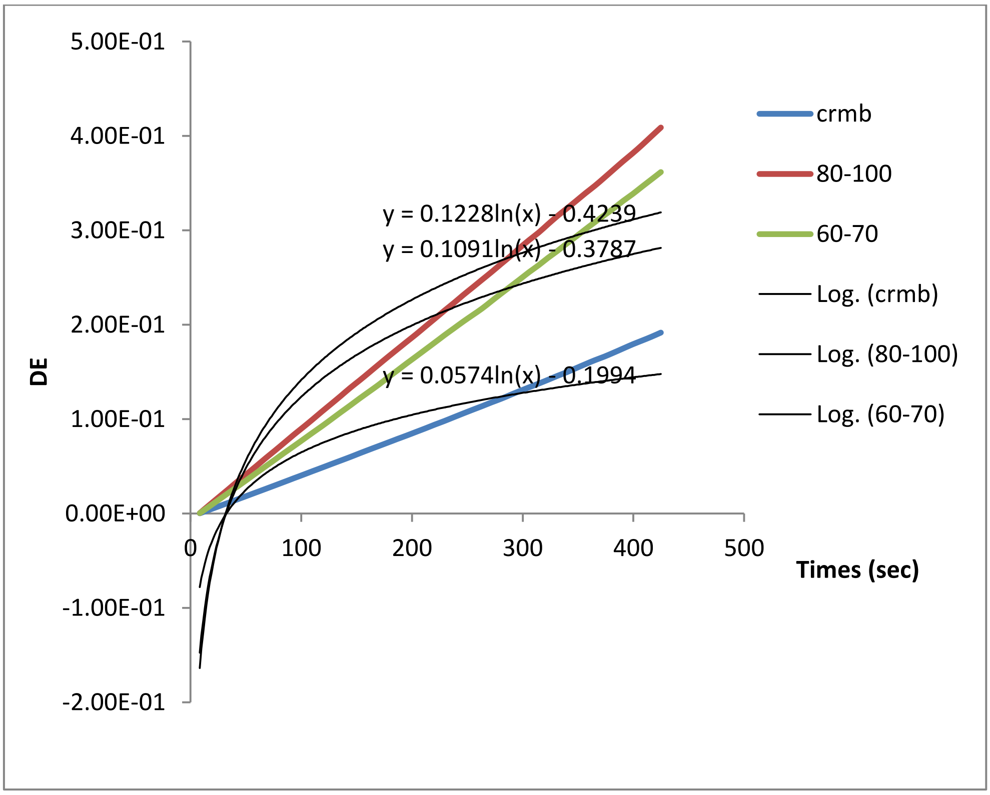

Figure (5.11): Relation between number of cycles and DE for PAV binders

Table (5) Fatigue Test Result

Type of Bitumen	Log Fatigue life	Fatigue life	
80-100	0.1228ln(DE)-0.4239	Nf = 0.6545 (1/DE)^-0.1228	
		K1=0.6545	K2=-0.1228
60-70	0.1091ln(DE)-0.3787	Nf = 0.6847 (1/DE)^- 0.1091	
		K1=0.6847	K2=-0.1091
CRMB	0.0574ln(DE)-0.1994	Nf = 0.8192 (1/DE)^-0.0574	
		K1=0.8192	K2=-0.0574

Fatigue parameter K_1 and K_2 are used to compare between two materials,

- the higher K_1 the higher fatigue life and
- The lower K_2 higher dissipated energy the lower fatigue life.

In conclusion from laboratory fatigue test, the fatigue behavior of crumb rubber modified bitumen was found to be significantly improved compared to base bitumen. Crumb rubber modified bitumen has the higher fatigue life; followed by 60-70 as observed from laboratory fatigue test results. On the other hand, 80-100 grade bitumen shows no significant effect in fatigue life.

CHAPTER 6

CONCLUSION

&

REFERENCES

6.1. CONCLUSION

The main objectives of this research were to characterize the bituminous binders. The additions of modifier to the pure bitumen improve the viscoelastic behavior of the bitumen and change its rheological properties. Also the process of ageing improves the rheological properties as compared to aged ones. After conducting laboratory tests on binders and after analyzing the data and comparing the results, the following conclusions have been drawn:

- From the results, it appears clearly that when the rubber was added to the base bitumen phase angle decreases which directly affects the elastic recovery properties and helps the bitumen to be fully recovered when the load is removed and helps for resisting rutting.
- A decrease in phase angle is generally observed after ageing tests, when compared with the original ones. Since phase angle is a measure of the ratio between loss modulus and storage modulus, the increased phase angle (loss tangent) implies that ageing leads to a greater increase in storage modulus (elastic component, G`). The high value of G` is an advantage since it will not cause further rutting during service.
- From MSCR tests, it is observed that the elastic recovery in 80-100 binder is much less than that of CRMB. So, the 80-100 binder does not recover its original shape when tension is released but CRMB recovers to its original when load is withdrawn at a faster rate. This degree of elastic recovery was used as an indicator of permanent deformation in pavement materials.
- The above performance related tests indicate that CRMB is superior to 80/100. The result showed significant improvement in fatigue behavior of modified binder used when compared with the neat binders.

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